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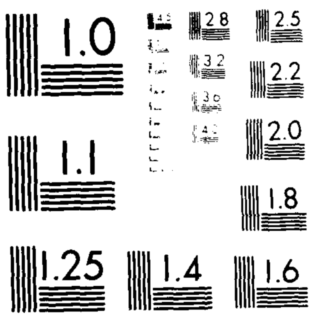

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SPATIAL CONTRAST SENSITIVITY WITH EXTREMELY SMALL PUPILS

ALLAN J. PANTLE

MIAMI UNIVERSITY

DECEMBER 1983

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AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Charles Bates

CHARLES BATES, JR.
Director, Human Engineering Division
Air Force Aerospace Medical Research Laboratory

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Six subjects were fitted with soft contact lenses with 1.5 mm pupil openings. Spatial contrast threshold function (CTF) were measures on these subjects and comparisons were made between the CTF when wearing the 1.5 mm contact lens and normal contact lens. The spatial CTF's were determined for 8 spatial frequencies between 0.75 and 21 cycles per degree of visual angle using the forced choice staircase procedure. The purpose of this experiment was to determine if changes in CTF from drug induced miosis was comparable to miosis produced by artificial pupil in contact lens.

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PREFACE

This report was prepared in support of the Human Engineering Division, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433. The literature review was conducted by MacAulay-Brown, Inc., 3989 Colonel Glenn Highway, Fairborn, Ohio 45324. The project was conducted in accordance with the "Technical and Analytical Support for the Air Force Chemical Defense Analysis Program," Task 81-04, "Pretreatment Psychomotor Studies." The work was accomplished during June, July, and August of 1982 under Air Force Contract F33615-80-C-0514.

The contribution of Captain Ronald Yates in reviewing the report is gratefully acknowledged.

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INTRODUCTION

Experiments performed by the Air Force Aerospace Medical Research Laboratory, Human Engineering Division with diisopropyl fluorophosphate to simulate the effects of low doses of organophosphorous nerve agents on vision have shown a decrease in spatial contrast threshold functions between 2 and 10 cycles per degree. The main known physiological effect of nerve agents on the eyes is to produce miosis with pupil sizes decreasing to diameters as small as 1 to 2 millimeter. As a result of the above experimental findings, an experiment was designed to determine whether decreases in pupil diameter produced by a contact lens with a pinhole aperture would produce changes in spatial contrast threshold similar to those produced by nerve agents or whether other factors were responsible for the changes in spatial contrast threshold.

METHODOLOGY AND RESULTS

The goal of this research was to assess the effects of an extremely small pupillary opening on pattern vision. To this end we compared spatial contrast threshold functions (hereafter CTFs) of observers (1) while wearing contact lenses and using their natural pupils, and (2) while wearing contact lenses which were opaque except for a small clear "peephole" or pinhole opening (artificial pupil). Both the regular and pinhole lenses were soft contact lenses. Both types contained an optical correction appropriate for their wearer as determined by routine optometric examination. The pinhole lenses were custom manufactured by the Narcissus Foundation of Daly City, California. The "peephole" in the pinhole lenses was 1.5 mm in diameter and coincided with the center of an observer's natural pupil when the lenses were worn.

Spatial CTFs consisted of measurements of the minimum contrast (contrast threshold) required to detect sinusoidal gratings with 8 spatial frequencies in the range 0.75 to 21 c/deg. The gratings had a space-average luminance of 2.5 mL and were seen through a rectangular hole in a spatially uniform cardbord screen. The hue of the cardboard screen approximately matched that of the gratings. Its luminance was 1.5 mL. Subjects viewed the display binocularly from a distance of either 112 cm or 224 cm. At the 112-cm viewing distance the gratings subtended a visual angle of 4 deg, 30 min horizontally and 3 deg, 50 min vertically; the cardboard screen, 11 deg vertically and 9 deg horizontally. All dimensions were half as large at the 224-cm viewing distance. At the short viewing distance, we measured contrast thresholds for gratings of 0.75, 1.5, 3 and 6 c/deg; at the long viewing distance, thresholds for gratings of 6, 9, 12, 18 and 21 c/deg. All gratings were made to drift at the very slow rate of 0.08 Hz so that the position (spatial phase) of the grating changed from trial to trial and kept the subject from using any local luminance changes to detect the grating. A small black fixation spot was provided in the center of the display.

Contrast thresholds were determined by a psychophysical, forced-choice, staircase procedure. With this procedure there was a test trial every 5 sec. Each test trial consisted of two 1.75-sec intervals separated by a period of 2 sec. Each interval was accompanied by an auditory tone, and a test grating was present in one of the pair of test intervals according to a random schedule. The grating was ramped on and off over 0.25 sec to avoid sharp temporal transients. The subject's task was simply to identify the interval containing the test grating. A staircase (threshold tracking series) started with a contrast set well above the subject's threshold. Thereafter the contrast was increased or decreased depending upon the correctness of the subject's response on each forced-choice trial. After an adequate number of reversals in the direction of contrast change over trials, the staircase series was terminated and the contrast threshold computed from the reversal points.

Two CTFs, one with regular lenses and one with pinhole lenses, were obtained for each of six observers (PL, CL, WG, KB, KP and KK). Contrast thresholds (in percent contrast) at each spatial frequency are given in the accompanying table for each of the six observers. The ratio of the pinhole lens threshold to the regular lens threshold (P/R ratio) for each observer at each spatial frequency is also provided. The geometric means of the thresholds of the individual observers at each spatial frequency were computed and are shown in the table (M6 heading) and plotted in Fig. 1. The standard error of a mean threshold was typically about 10 percent. It is clear from the table and Fig. 1 that the contrast threshold was higher with pinhole lenses than with regular lenses at all spatial frequencies.

Table I. Spatial Contrast Thresholds

SP FREQ		0.75	1.5	3	6-S	6-L	9	12	18	21
PL	R	0.49	0.36	0.26	0.43	0.32	0.88	1.40	2.25	11.23
	P	0.95	0.64	0.93	1.66	1.21	1.91	5.66	7.10	17.54
	P/R	1.94	1.78	3.58	3.86	3.78	2.17	4.04	3.16	1.56
CL	R	0.59	0.20	0.39	0.46	0.39	0.98	1.53	3.26	8.19
	P	0.72	0.51	0.54	1.11	1.53	2.02	1.91	6.66	9.83
	P/R	1.22	2.55	1.38	2.41	3.92	2.06	1.25	2.04	1.20
WG	R	0.39	0.15	0.26	0.71	0.28	0.75	1.88	4.39	4.31
	P	0.69	0.32	0.60	2.12	1.39	2.21	2.64	5.85	7.40
	P/R	1.77	2.13	2.31	2.99	4.96	2.95	1.40	1.33	1.72
KB	R	0.34	0.29	0.24	0.41	0.37	0.67	0.84	2.69	4.36
	P	0.49	0.33	0.43	1.56	0.94	2.32	2.51	4.22	7.75
	P/R	1.44	1.14	1.79	3.80	2.54	3.46	2.99	1.57	1.78
KP	R	0.58	0.36	0.30	0.49	0.41	0.66	1.34	2.19	3.97
	P	1.00	0.73	0.66	1.57	0.74	2.28	4.18	5.28	9.45
	P/R	1.72	2.03	2.20	3.20	1.80	3.45	3.12	2.41	2.38
KK	R	0.40	0.21	0.26	0.41	0.39	0.42	1.04	2.96	3.77
	P	0.86	0.58	0.79	1.79	0.77	1.66	1.64	8.29	16.44
	P/R	2.15	2.76	3.04	4.37	1.97	3.95	1.58	2.80	4.36
	R-WF	0.58	0.44	0.44	1.20	1.60	2.48	4.61	8.58	13.70
	R-WF/R	1.45	2.10	1.69	2.93	4.10	5.90	4.43	2.90	3.63
KT	R	0.52	0.23	0.30	0.44	0.46	1.55	2.09	5.03	9.59
	R-WF	0.45	0.36	0.64	2.13	1.35	3.50	6.44	19.24	-----
	R-WF/R	0.87	1.57	2.13	4.84	2.93	2.26	3.08	3.83	-----
M6	R	0.46	0.25	0.28	0.48	0.36	0.70	1.29	2.87	5.44
	P	0.76	0.49	0.64	1.61	1.05	2.05	2.81	6.09	10.74
	P/R	1.65	1.96	2.29	3.35	2.92	2.93	2.18	2.12	1.97
M2	R	0.46	0.22	0.28	0.42	0.42	0.81	1.47	3.86	6.01
	R-WF	0.51	0.40	0.53	1.60	1.47	2.95	5.45	12.85	(13.70)
	R-WF/R	1.11	1.82	1.89	3.81	3.50	3.64	3.71	3.33	(3.63)

OPTRONIX

KK	R	0.93	0.40	0.55	0.56	----	0.72	1.07	-----	-----
KT	R	0.65	0.18	0.25	0.44	----	0.93	1.58	-----	-----

ABBREVIATIONS
- S: SHORT VIEWING DISTANCE
- L: LONG VIEWING DISTANCE
- R: REGULAR CONTACT LENSES
- P: PINHOLE CONTACT LENSES
- WF: WITH NEUTRAL DENSITY FILTER
- PL, CL, WG, KB, KP, KK, KT: SUBJECTS
- M6: MEAN DATA FOR SIX SUBJECTS
- M2: MEAN DATA FOR TWO SUBJECTS

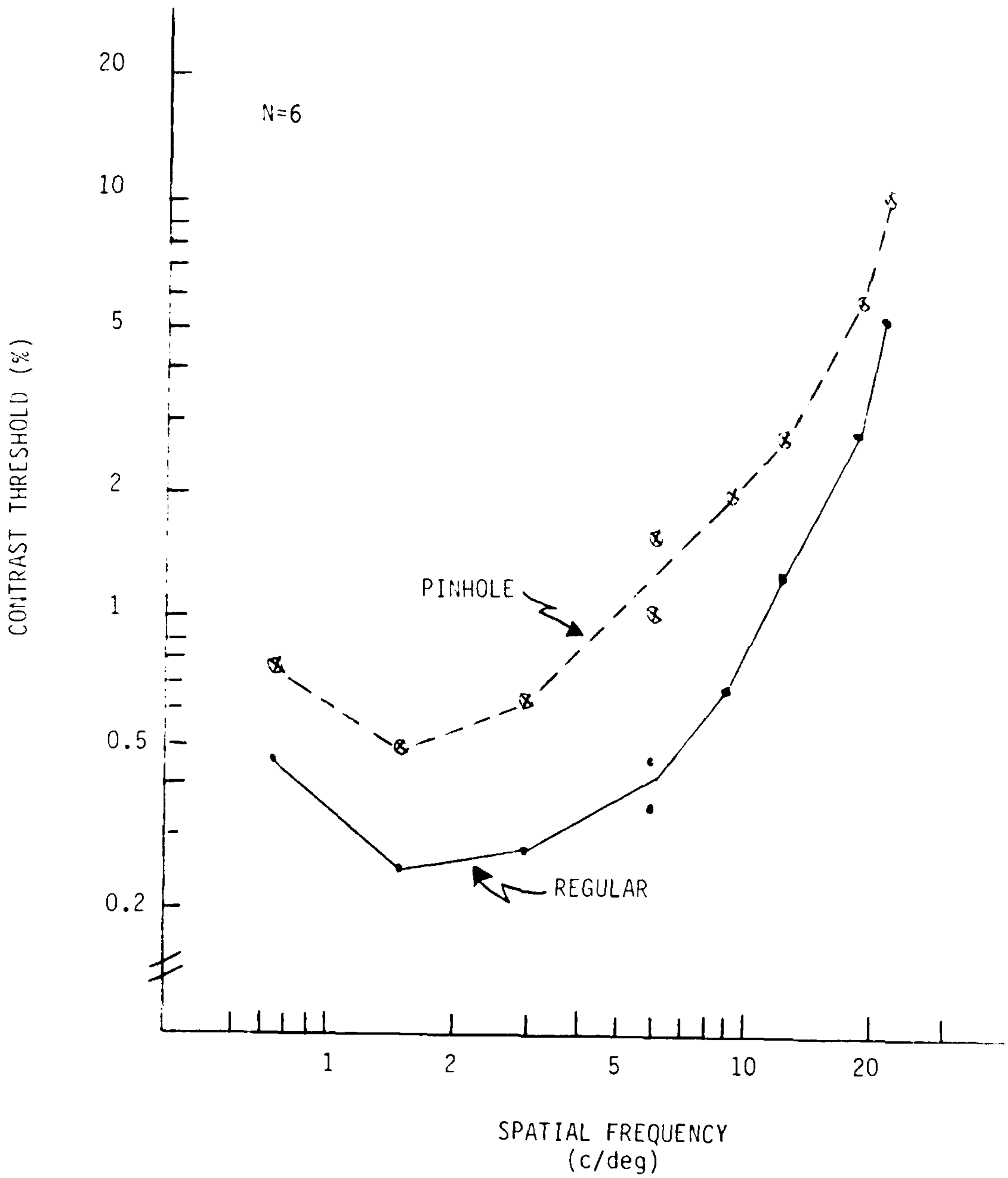

Figure 1. Spatial Contrast Threshold Normal Contact Lens and Pinhole Apertures

The amount by which the pinhole lens threshold exceeded the regular lens threshold at each spatial frequency (M6, P/R ratio in the table) is plotted in Fig. 3 as the solid function. The largest differences were obtained in the 5-10 c/deg region (approximately three-fold increases of threshold) with smaller differences at lower and higher spatial frequencies.

The retinal illumination provided by the pinhole contact lenses would have been less than that provided by the regular lenses. For the conditions which prevailed during the experiment, we calculated the reduction to be approximately a factor of 8. Therefore, we made supplementary measurements of contrast thresholds for two observers while they viewed the grating display through 0.9 neutral density filters with their regular contact lenses. These thresholds are provided in the accompanying table (subjects KK and KT), and the geometric means of the contrast thresholds for the two subjects (regular lenses) both with and without the neutral density filters are also shown in the table (M2) and plotted in Figure 2. As has been found before (Van Nes and Bouman, 1967), a reduction in average retinal illumination leads to an increase of contrast thresholds, and the increases (ratio of threshold with filters to threshold without filters, R-WF/R) are less at low than at high spatial frequencies (Fig. 3, dashed curve). The relatively similar changes of threshold which occurred at low-to-intermediate spatial frequencies with the use of the neutral density filters and with the wearing of the pinhole lenses suggest that the reduction of retinal illumination alone is sufficient to account for the low-to-intermediate spatial frequency threshold elevations which accompanied the wearing of the pinhole lenses. The threshold elevations in the intermediate-to-high spatial frequency range cannot be similarly explained. The elevations produced by the pinhole lenses in the high-frequency region were smaller than one would expect from a simple reduction of retinal illumination. The difference between the filter and pinhole functions at high spatial frequencies (Fig. 3) is probably attributable to a higher quality retinal image in the pinhole lens condition. The optical spread function for a pupil size of 1.5 mm (diameter) is narrower than that for a pupil size of 4-5 mm (the expected value in the filter condition) (Campbell and Gubisch, 1966). The narrower spread function would tend to attentuate the threshold elevations due to reduced retinal illumination at high, but not at low spatial frequencies.

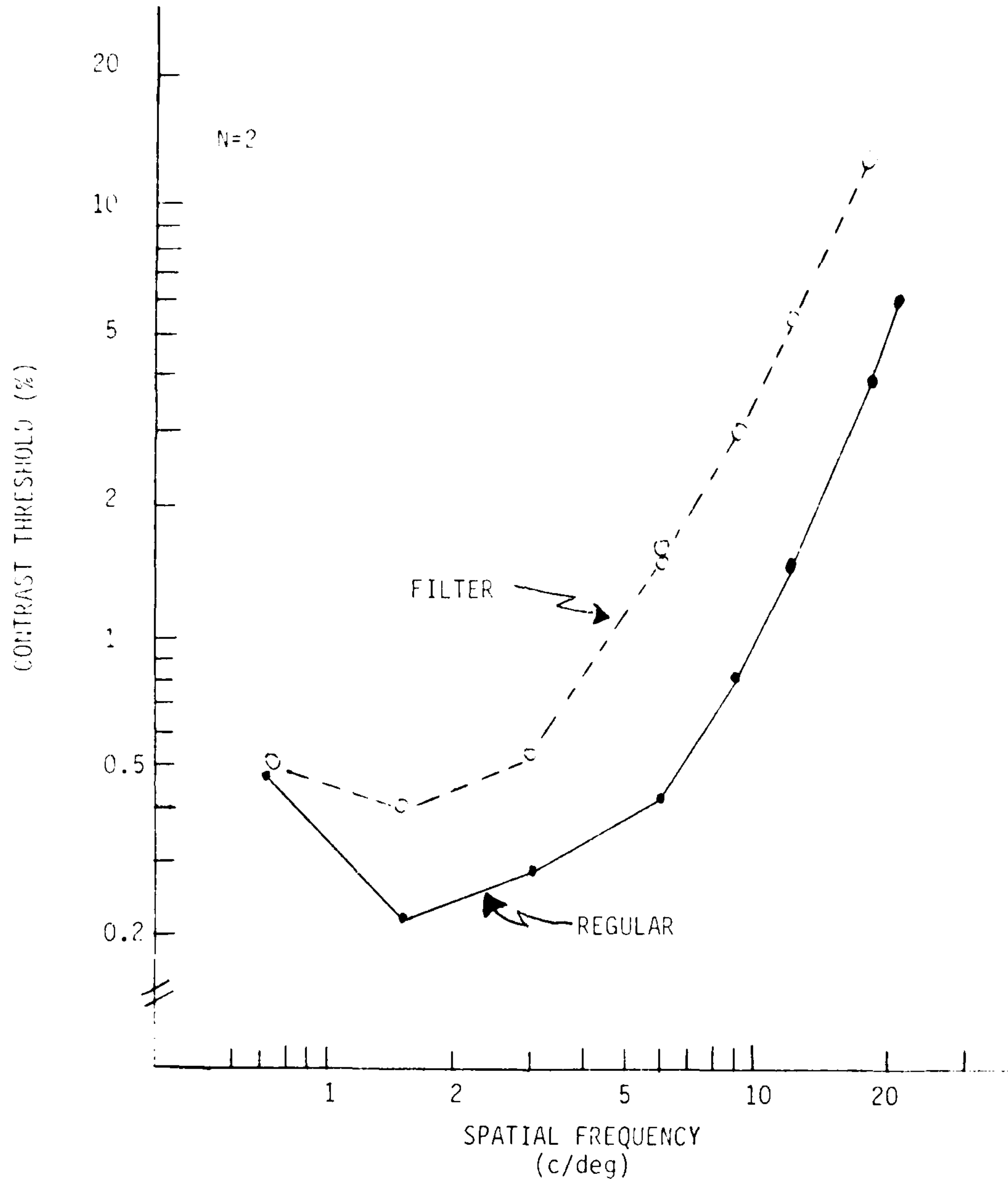

Figure 2. Spatial Contrast Threshold Normal Contact Lens and Neutral Density Filter

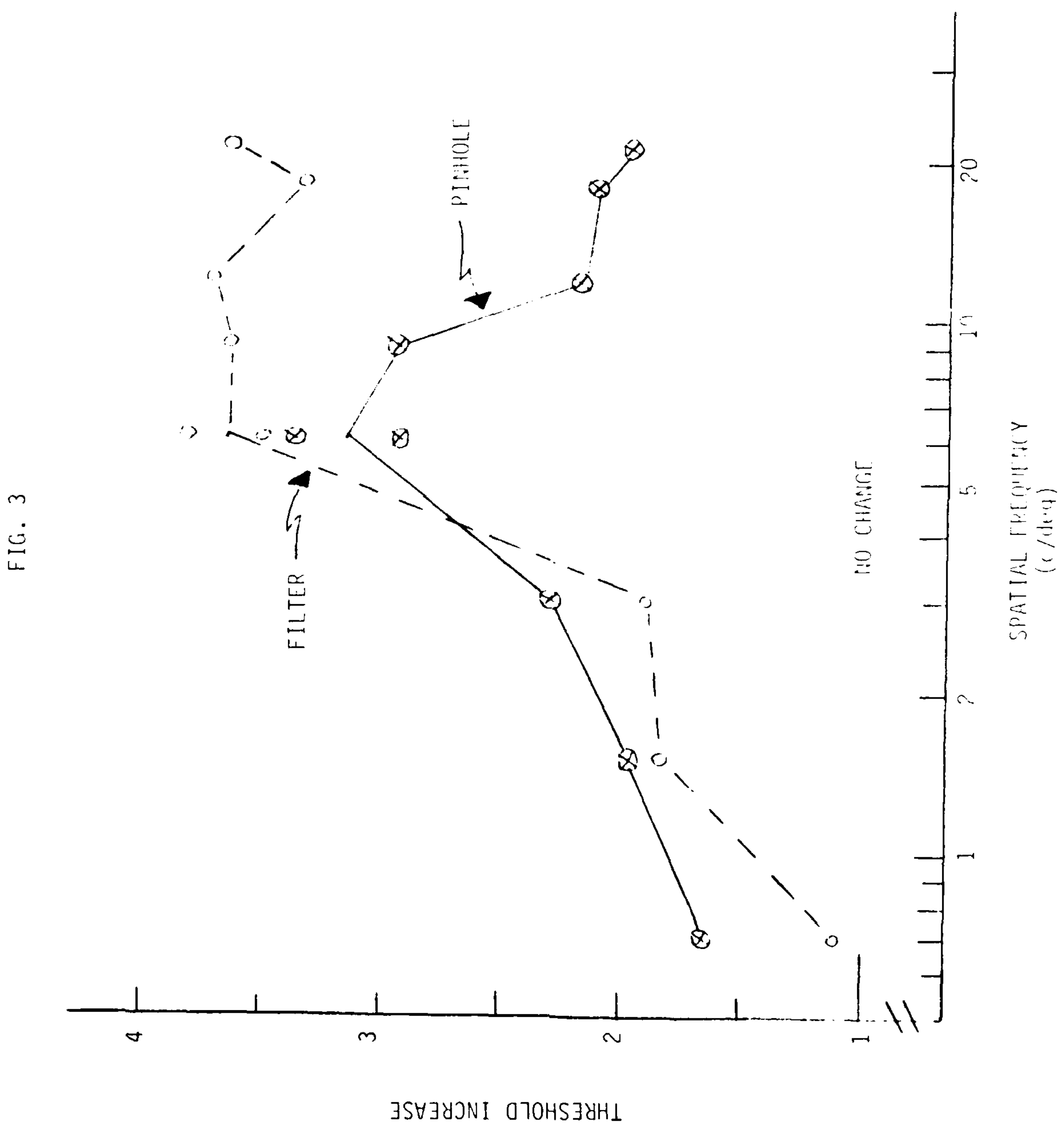

Figure 3. Comparison of Spatial Contrast Threshold Changes Produced by Pinhole Apertures and Neutral Density Filter

To summarize, at low photopic levels of illumination the wearing of pinhole contact lenses or the constriction of the pupillary opening of the eyes will produce a loss of contrast sensitivity, a loss that is most severe at intermediate spatial frequencies. The pattern of losses can be explained by two factors: (1) the loss of contrast sensitivity due to reduced retinal illumination, and (2) the narrowing of the optical spread function.

Measurements of CTFs obtained with the Optronix Vision Tester for two subjects (KK and KT) are also given in the accompanying table. KT's thresholds with the Vision Tester were almost identical to those we measured with our apparatus and procedure (under similar experimental conditions), while the CTF of KK measured with the Vision Tester was displaced to higher values. The psychophysical procedures which are available as standard programs on the Vision Tester are not criterion-free (we used the Ascending Method of Limits), and the adoption of a high threshold criterion could account for KK's higher thresholds with the Vision Tester. We found the contrast calibration procedure of the Vision Tester to be reliable (actual contrasts of 25.3 and 25.8 percent on two separate occasions when the instrument was nominally set at 25 percent). However, at high spatial frequencies (above about 10 c/deg at a viewing distance of 10 m) the scan lines of the display interfered with our external physical calibration of the display and with measurements of contrast thresholds (aliasing effects).

CONCLUSIONS

The results of this experiment show that some changes in CTFs produced by pinhole aperture lenses are like those produced by low doses organophosphorous agents to the visual system. The similarity suggests that the changes in CTFs produced by the agents might be caused by severe pupillary constriction leading to decreased illumination at the retina and a narrower optical spread function on the retina. If so, contact lenses with pinhole apertures could be used to simulate the visual effects of organophosphorous agents.

However, it must also be realized that the present results do not preclude the possibility that the CTF changes, and changes in visual function in general, which are produced by organophosphorous agents are caused by factors other than pupillary constriction, or to a combination of pupillary constriction and other factors. Moreover, the contact lenses do not simulate other vision-related effects, such as accommodative spasm and browache.

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